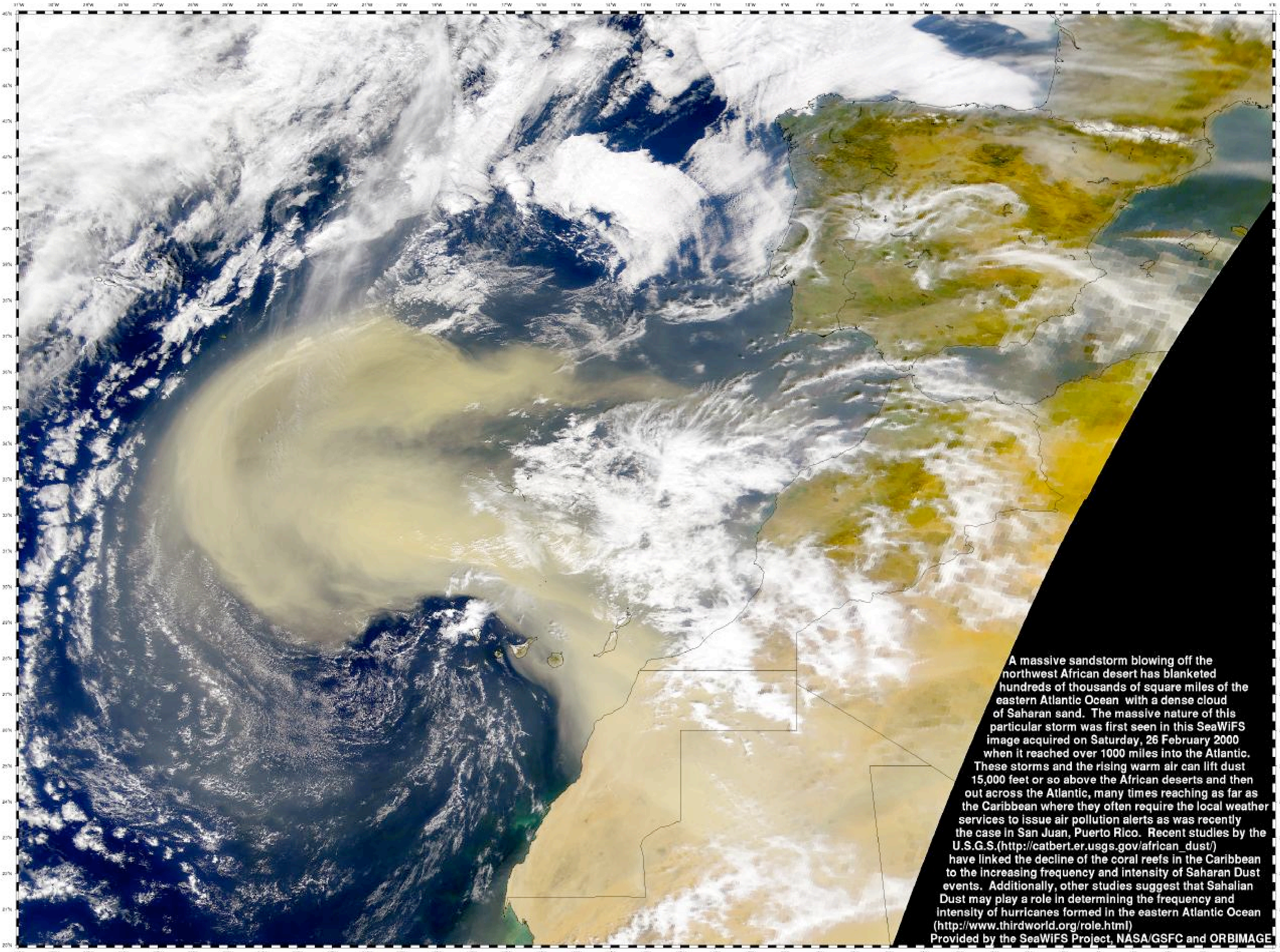
Climate sensitivity of natural mineral aerosols and sea salts in CAM: implications for climate and biogeochemistry

Natalie Mahowald

NCAR

With Sam Levis, J-F Lamarque, Masaru Yoshioka, Chao Luo, Phil Rasch, Charlie Zender, Xue Xie Tie, Bette Otto-Bliesner and others

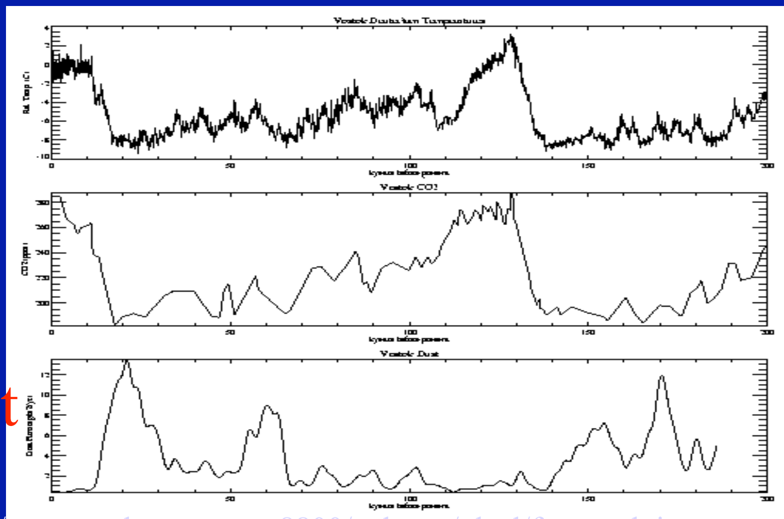

A massive sandstorm blowing off the
northwest African desert has blanketed
hundreds of thousands of square miles of the
eastern Atlantic Ocean with a dense cloud
of Saharan sand. The massive nature of this
particular storm was first seen in this SeaWiFS
image acquired on Saturday, 26 February 2000
when it reached over 1000 miles into the Atlantic.
These storms and the rising warm air can lift dust
15,000 feet or so above the African deserts and then
out across the Atlantic, many times reaching as far as
the Caribbean where they often require the local weather
services to issue air pollution alerts as was recently
the case in San Juan, Puerto Rico. Recent studies by the
U.S.G.S.(http://catbert.er.usgs.gov/african_dust/)
have linked the decline of the coral reefs in the Caribbean
to the increasing frequency and intensity of Saharan Dust
events. Additionally, other studies suggest that Sahalian
Dust may play a role in determining the frequency and
intensity of hurricanes formed in the eastern Atlantic Ocean
(http://www.thirdworld.org/role.html)
Provided by the SeaWiFS Project, NASA/GSFC and ORBIMAGE

Climate response of natural dust: large variability seen in observations

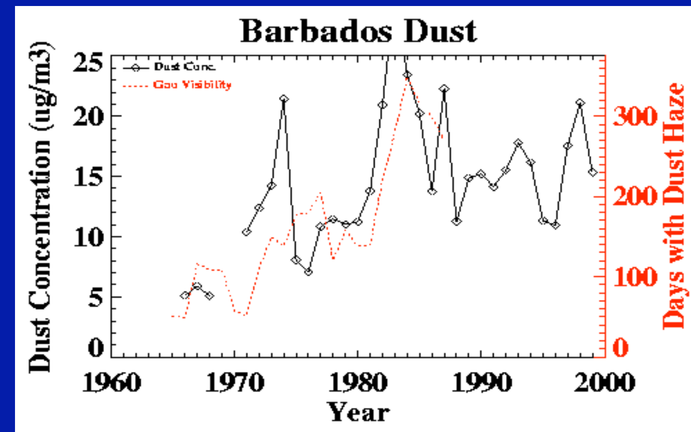
T

CO2

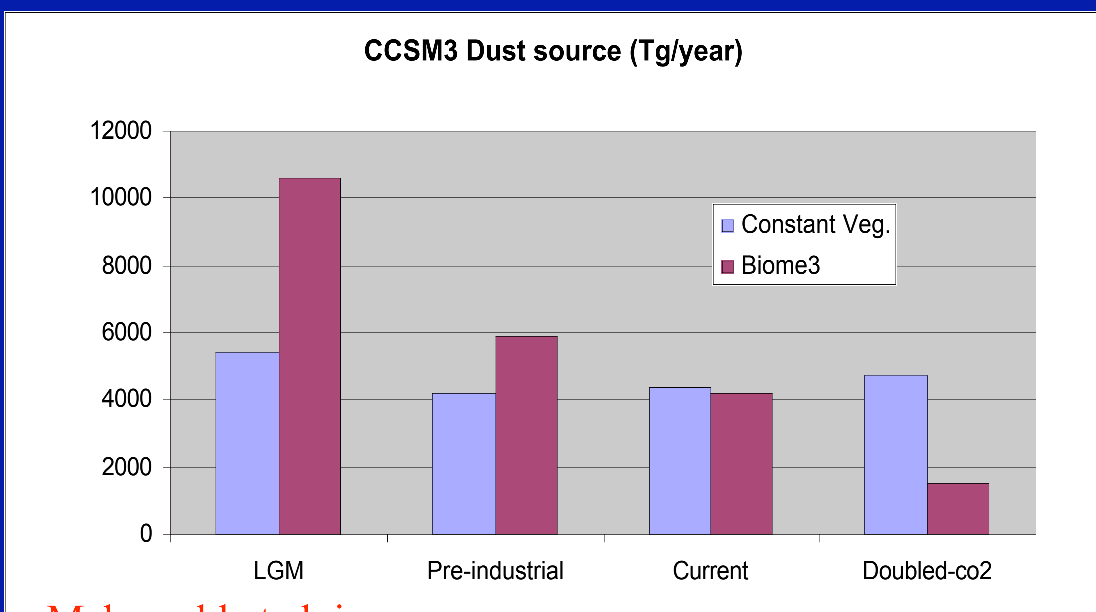
Dust



http://www.ngdc.noaa.gov:8800/paleo_s/plsql/ftpsearch.icecore;
Petit, et al., 1979; Jouzel et al., 1987; Chappelaz and Jouzel, 1992



Data from U. Miami, Mbouru et al., 1996



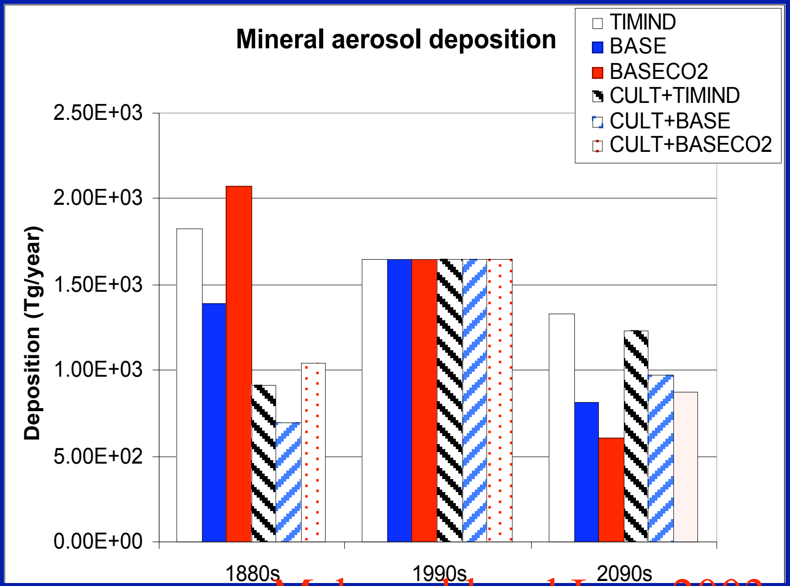
Mahowald et al. in prep

- Climate response largely from source area changes
- Consistent with Mahowald et al., 1999: Mahowald and Luo, 2003.
- E.g. Werner et al,2002 saw response to winds

•Humans perturb through climate change and land use impacts
•Current land use estimates vary from <10% to 50% (e.g. Tegen et al., 2004; Mahowald and Luo,2003; Mahowald et al., 2004)
•Need more studies (field studies) to determine conclusively.

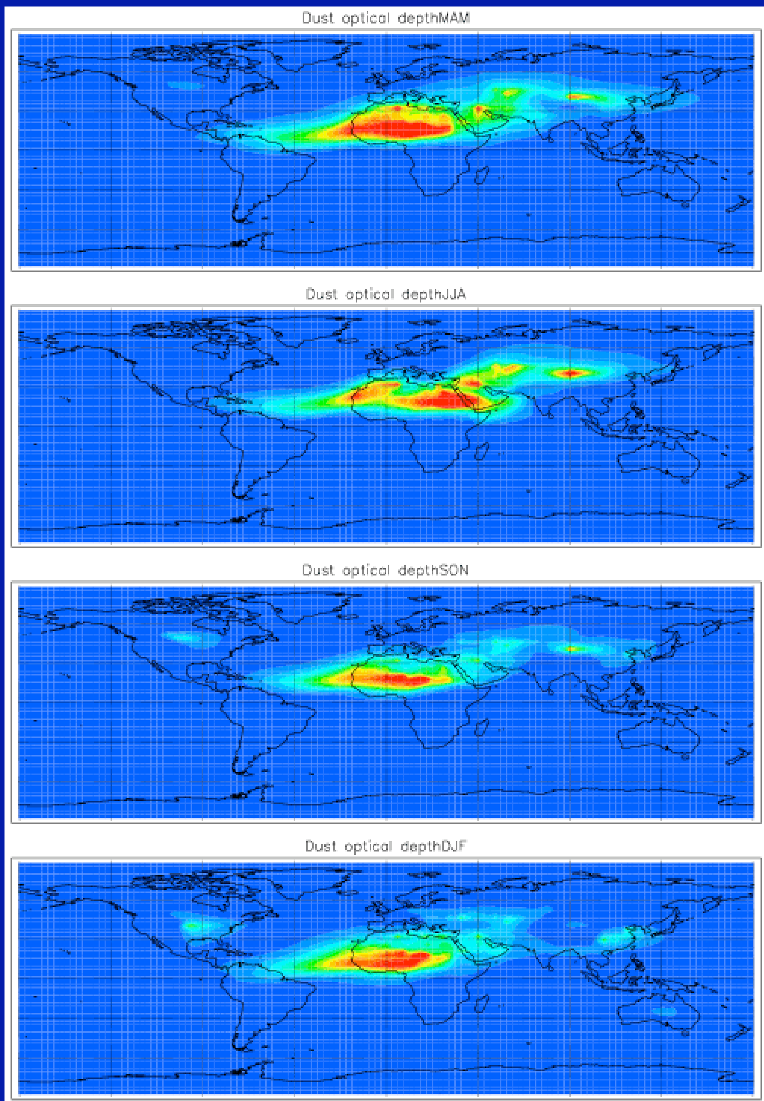
•Current climate anthropogenic dust (including climate impacts): up to 60% or humans caused decrease of 20% Mahowald and Luo, 2003.

•Future dust 20-60% lower than current climate (Mahowald and Luo, 2003) or +/-20% (Tegen et al., 2004) depending on model and assumptions

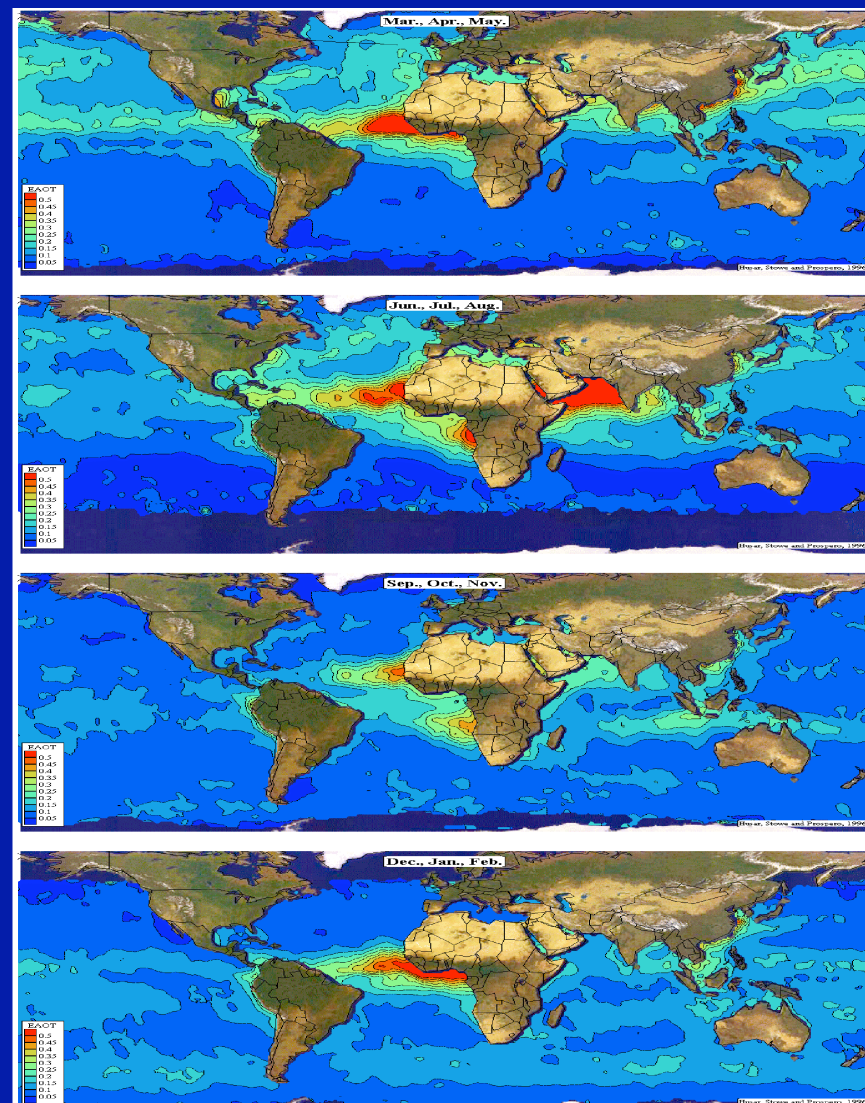


Mahowald and Luo, 2003

CAM optical depth



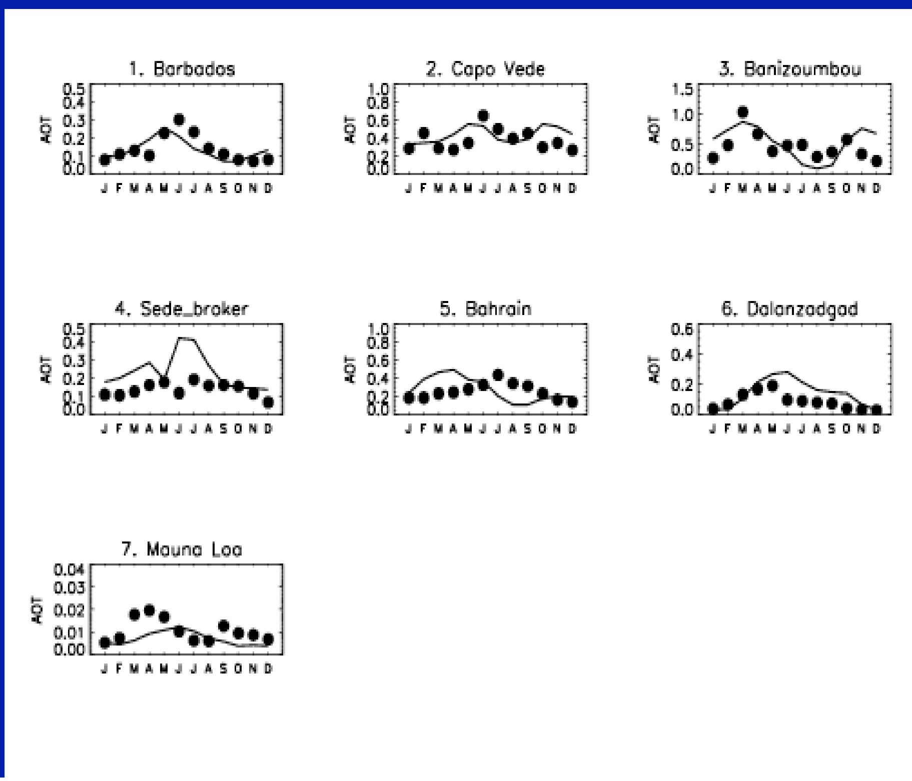
AVHRR optical depth

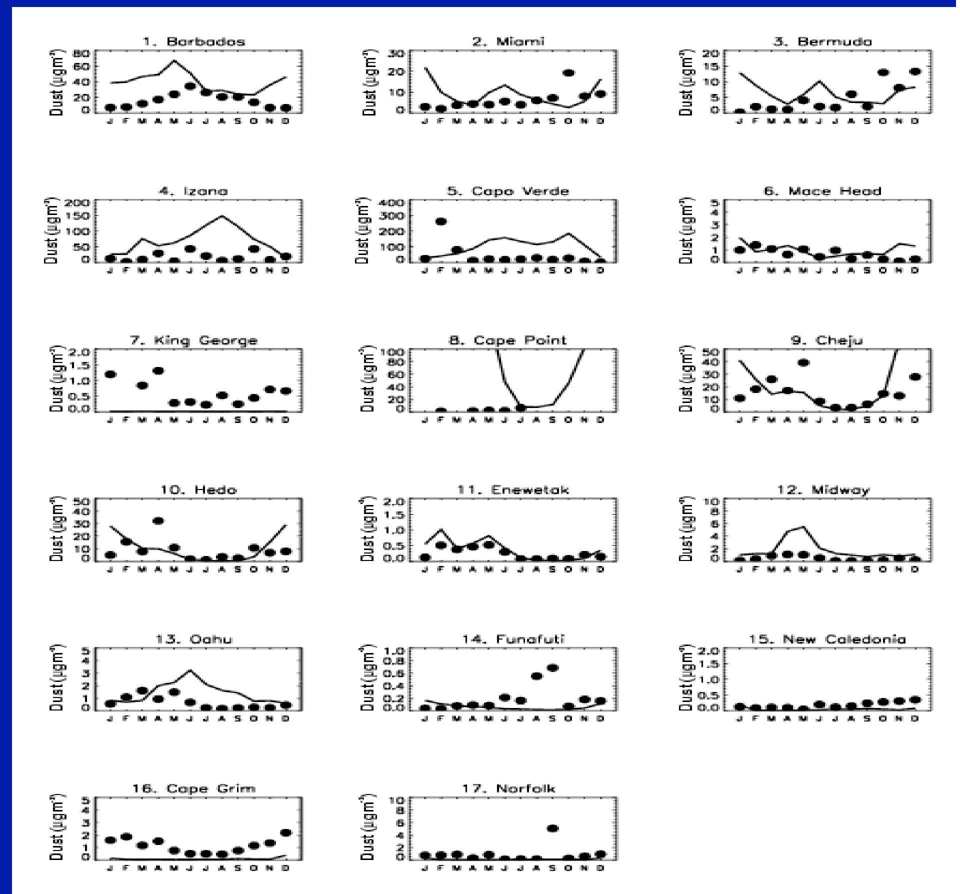


Model does ok at simulating dust climatology—but problems exist due to errors in GCM climatology (similar methodology does better in MATCH/NCEP simulations, e.g. Luo et al., 2003)

Surf. Conc. vs. CAM

Aeronet vs. CAM dust





Problems modeling dust variability in Earth System Models

- Lack of physical understanding
  - Human impacts on dust sources
  - Dry and wet deposition processes
  - Scaling issues (wind tunnel scale to global modeling scale
  - Response of different regions to climate change
- Bias in physical models
  - Winds (e.g. Tegen and Miller, 1998)
  - Precipitation/vegetation
  - Biogeochemical models will suffer from biases in physical models: are scientific conclusions suffering from biases?

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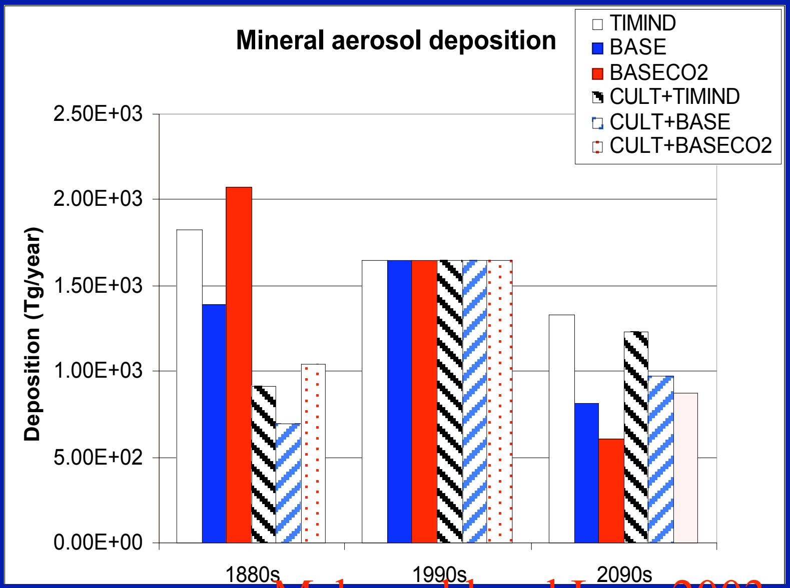
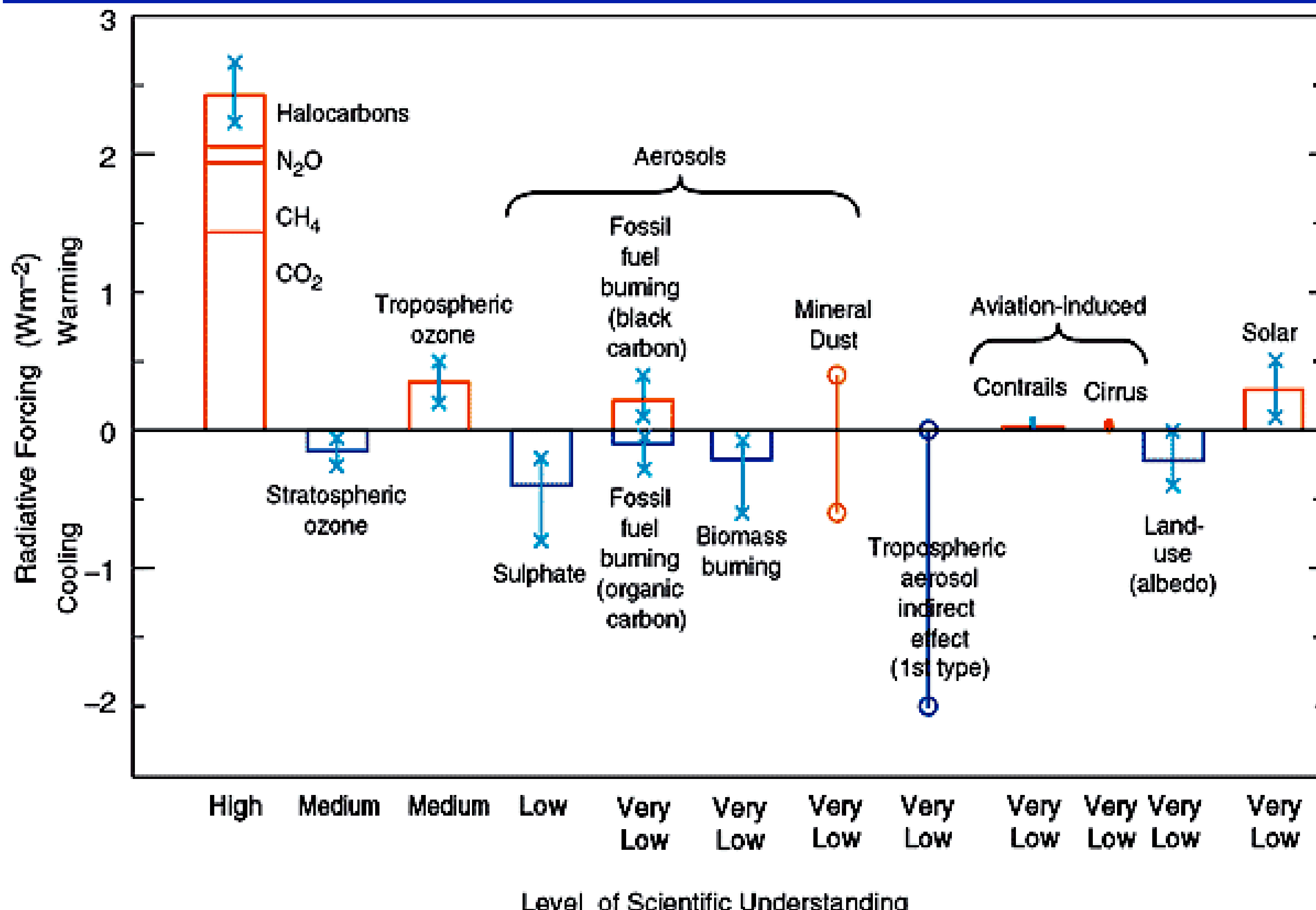


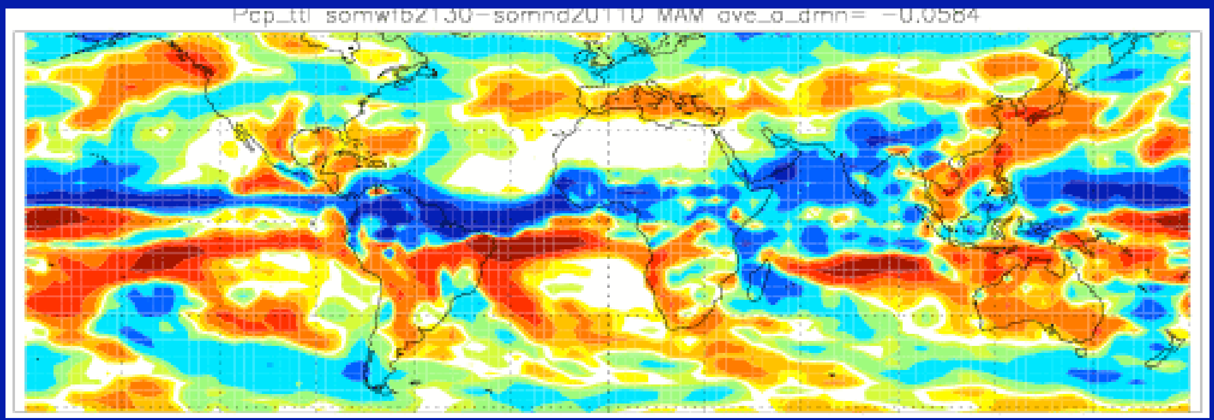
Mahowald and Luo, 2003



IPCC, 2001: Technical Summary

Response of climate to dust—direct radiation:

- Miller and Tegen, 1998 estimate in current climate: ~-1W/m2 surface forcing (large uncertainties due to mineralogy, size distribution, surface albedo (e.g. Sokolik and Toon, 1996; Liao and Seinfeld)



Yoshioka et al in prep

Dust visible radiative feedbacks cause a shift in ITCZ and intensify drought in Sahel. In contrast to wetter response in deserts seen in Perlwitz et al., 2001;Miller et al., 2003;2004.

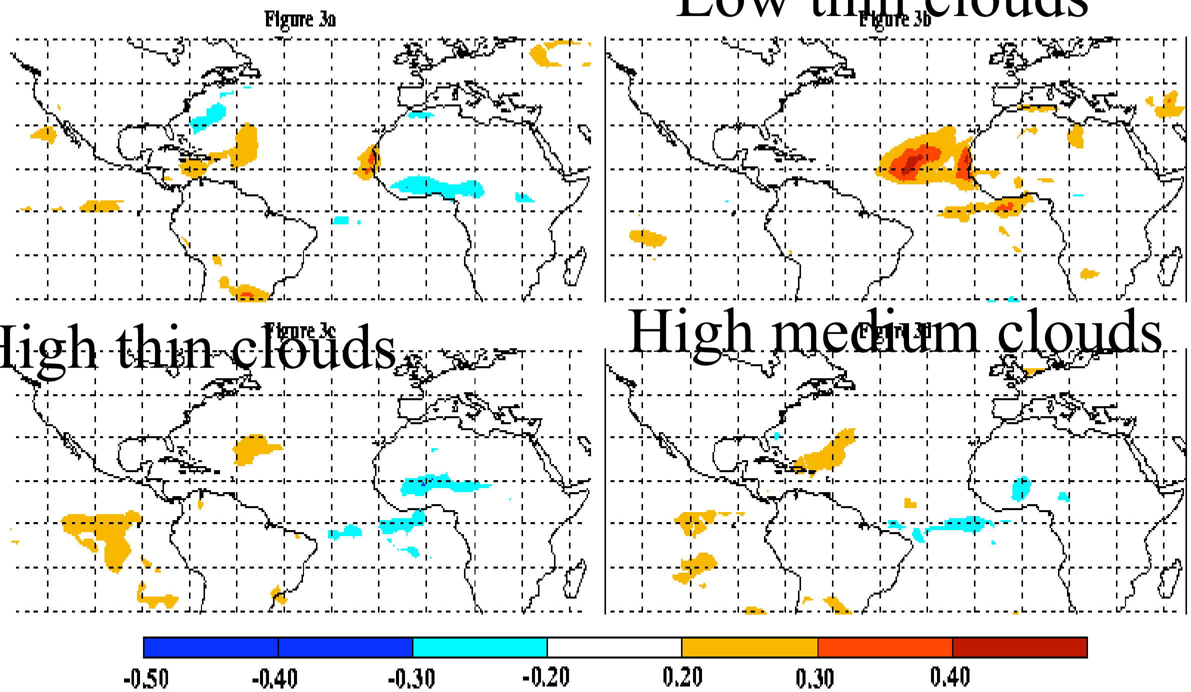
Climate response to dust: indirect forcing

All clouds

Low thin clouds

High thin clouds

High medium clouds



Correlations between ISCCP cloud amount and Barbdos surface concentration (similar relation in areal average TOMS AI) between –0.2 and 0.4 (only statistical significant values are shown). (Mahowald and Kiehl, 2003)

Response to dust seen in in situ and regional studies (Rosenfeld et al., 1996; 2001; de Mott et al., 2003)

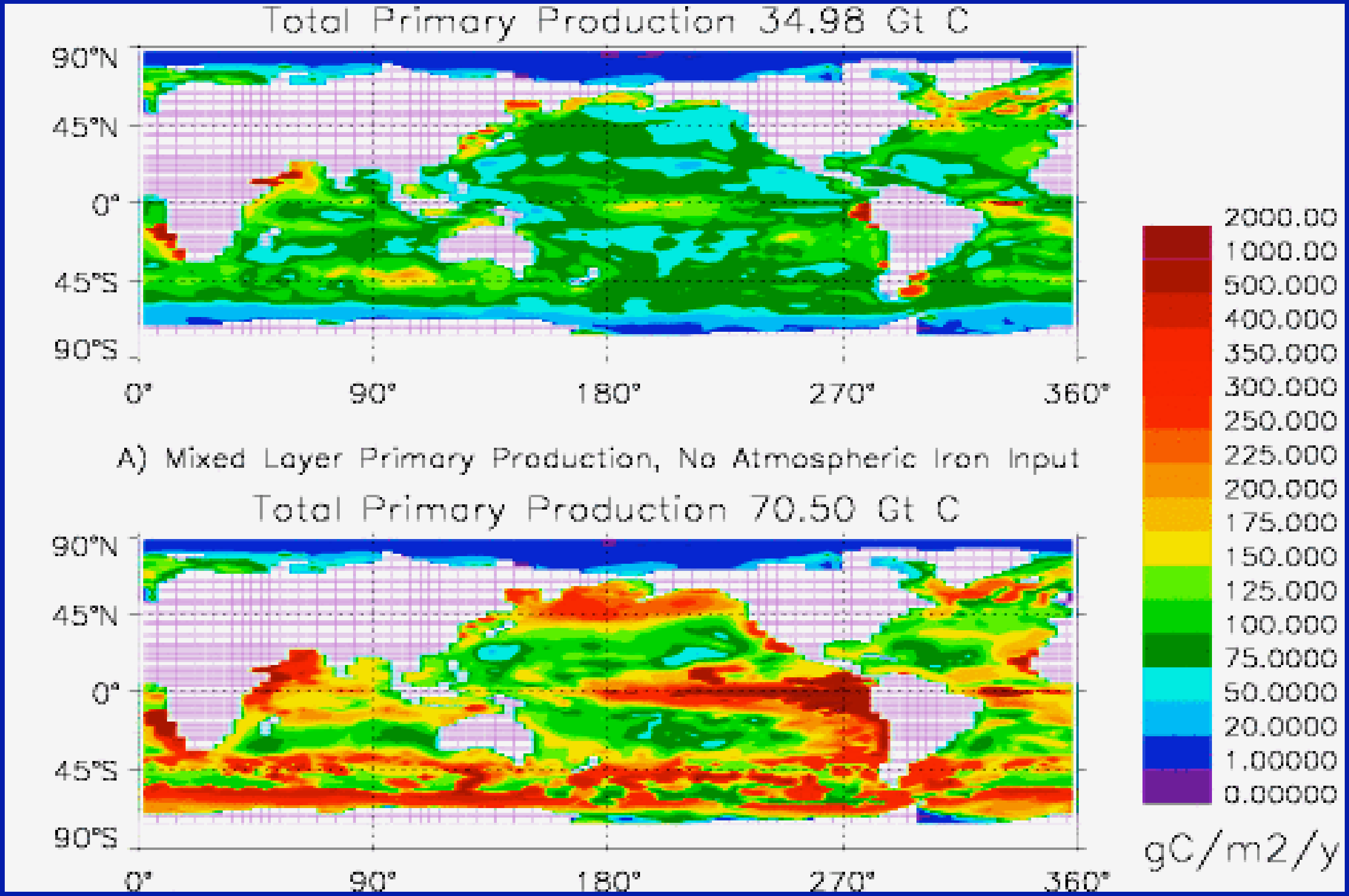
Problems including dust/climate feedbacks in earth system models

- Direct forcing:
  - uncertainties due to mineralogy, size distribution, surface albedo (e.g. Sokolik and Toon, 1996; Liao and Seinfeld)
  - Need to have location right (propogation of physical model biases)
- Indirect forcing
  - Cloud-aerosol interactions active area of research
  - Need all aerosols to get feedbacks of one type of aerosols

Ocean biogeochemistry response to mineral aerosol/iron inputs

Moore et al., 2002

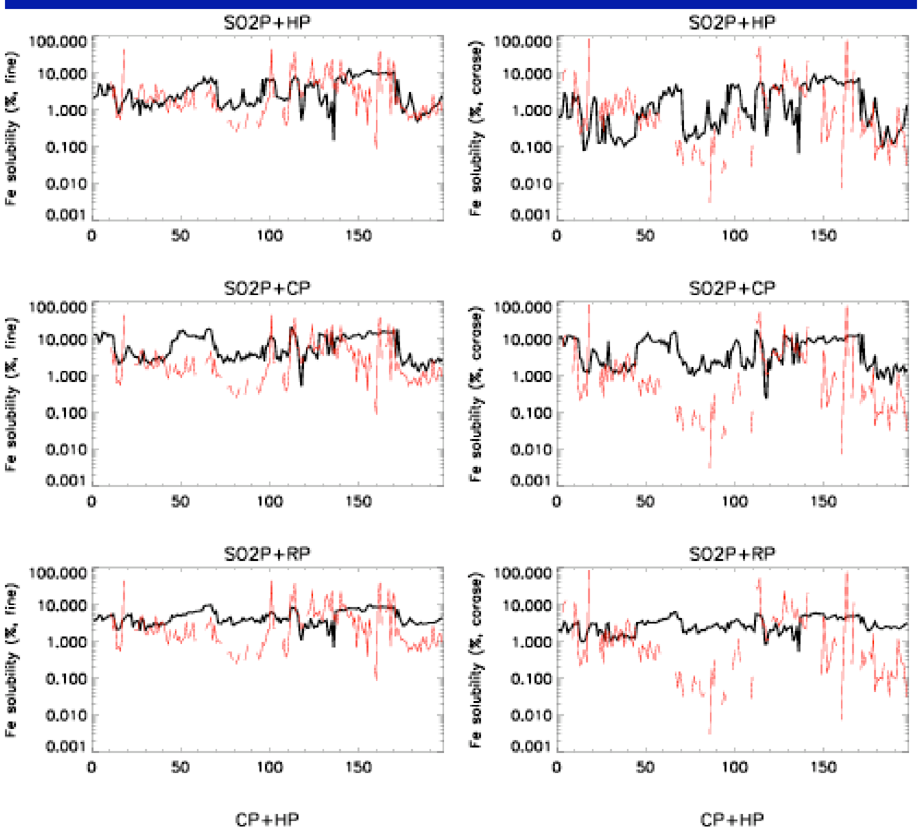
2x ocean primary productivity when atmospheric iron flux included (due to iron limitation incl. Diazatrophs)

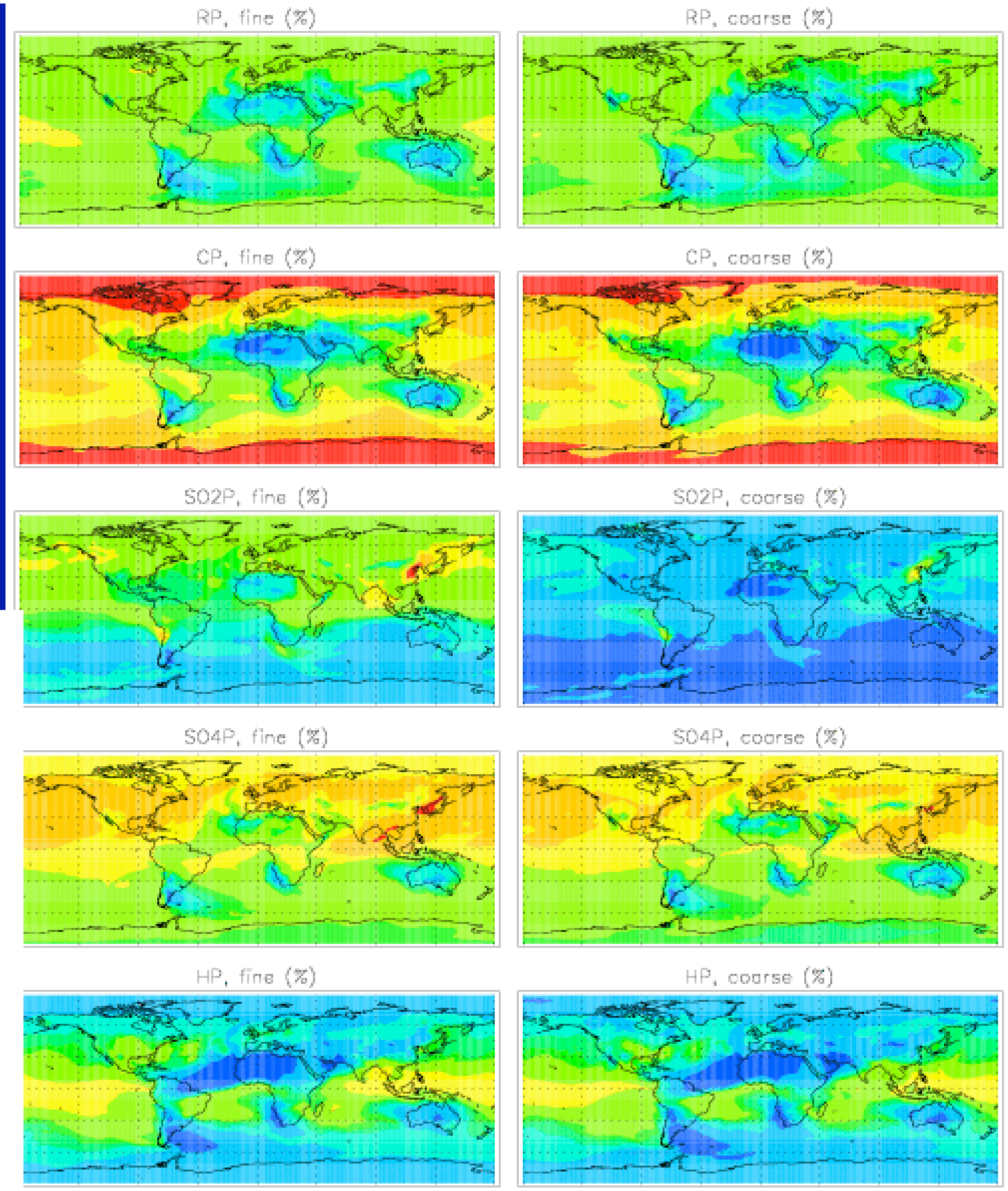


Bioavailability of iron in dust

- Not well understood—what state is bioavailable?
  - Biota can use Fe (III) (Barbeau et al., 2001), but Fe(II) more soluble
- Iron processed in atmosphere
  - Soils have <1% solubility while aerosols have <1% to 80%
  - High variability of iron solubility observed in atmosphere
- Mechanisms not well understood:
  - Cloud processing
  - Solar radiation
  - Sulfur chemistry
  - Organic acid chemistry

•Analysis suggests: Cloud processing and sulfur chemistry best matches data (Hand et al., 2004; Luo et al., in prep)





Luo et al in prep

Ocean biota response to iron inputs

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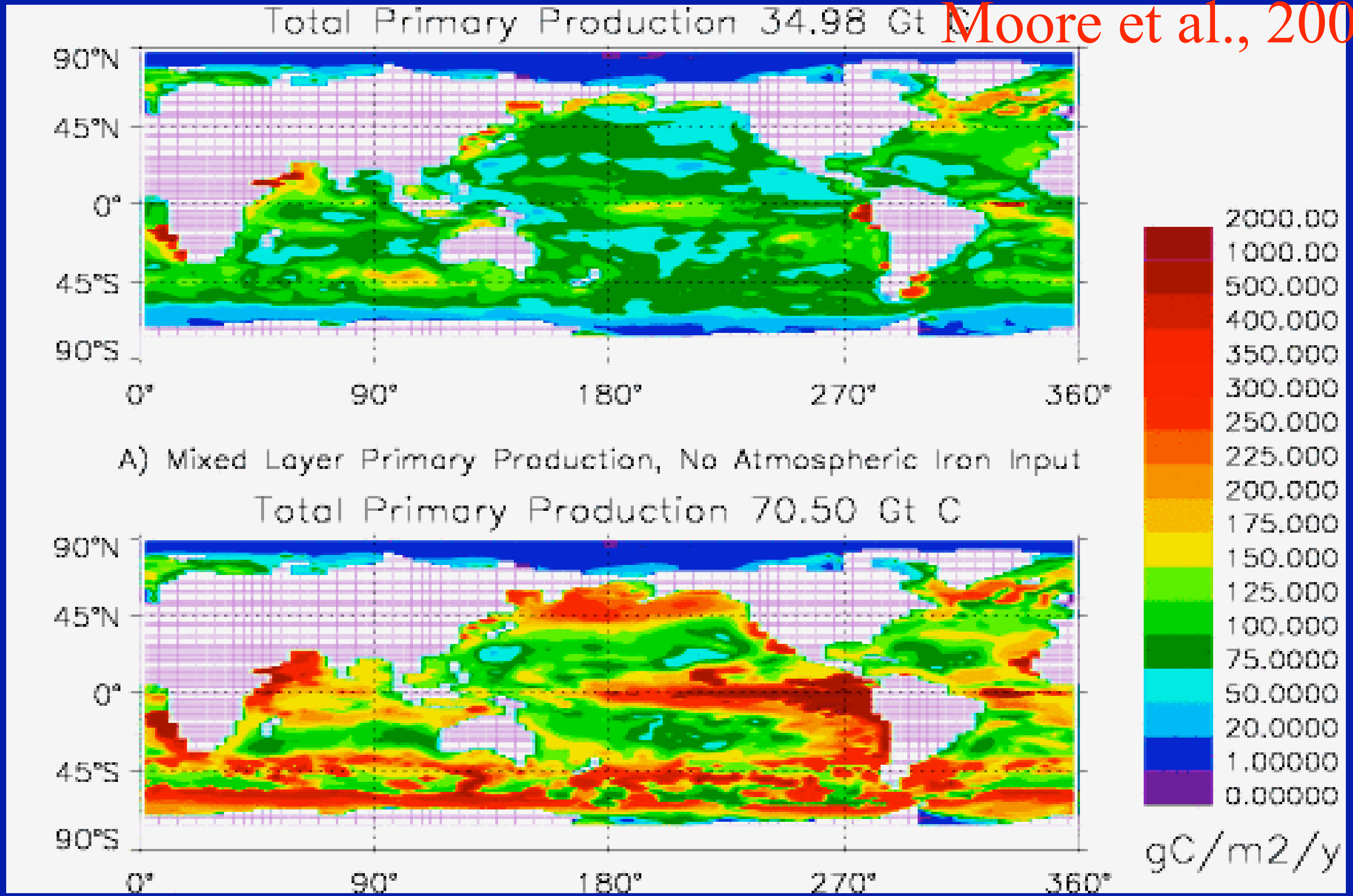


NCAR-CCSM3 planned coupled carbon experiments to include iron feedbacks on ocean biogeochemistry and nitrogen deposition feedbacks on terrestrial biosphere. (Models in place, spin-up and coupling in progress: Doney/Moore/Thornton/Lamarque/Mahowald)

Problems incorporating dust/ocean biogeochemistry feedbacks

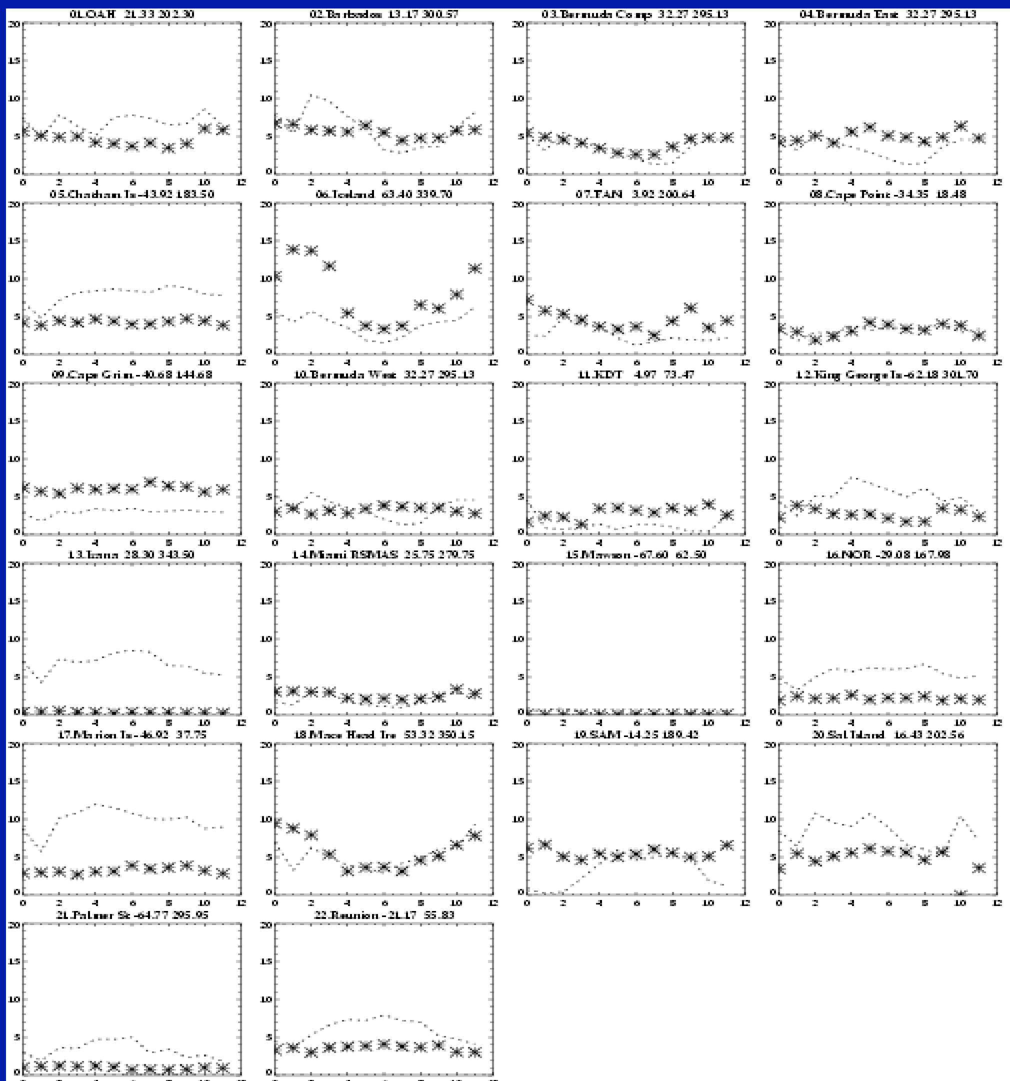
- Uncertainty in processes:
  - Uncertainty in iron processing in atmosphere and iron solubility deposition distributions
  - Uncertainty in iron bioavailability processes
  - Uncertainty in iron impacts on ocean biota
    - Iron limitation
    - Nitrogen fixation processes
- Model error propagation: dust deposition, iron availability, ocean biogeochemistry impacts

NCAR-CCSM3 planned coupled carbon experiments

- Terrestrial biogeochemistry (CLM-CN) nitrogen limited
- Ocean biogeochemistry iron limited
- Mineral aerosol interactive
- Atmospheric chemistry (to get nitrogen deposition to land)

(Models in place, spin-up and coupling in progress:
Doney/Moore/Thornton/Lamarque/Mahowald)

Sea Salt comparisons at stations



Sensitivity to climate: Global sea-salts stay within 5% of current for LGM, preindustrial, and 2x CO_2.

Ice core records of sea salts may be indicating sea ice extent and not sea salts (Wolff et al., 2003)

Dust in earth system models

- Dust important climate indicator
  - Very sensitive to climate changes
  - May respond to human interactions
- Dust important climate forcing mechanism
  - Direct and indirect radiative effects
  - Ocean (and terrestrial) biogeochemistry
- Efforts towards fuller integration in NCAR CCSM (and other climate centers).